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LIGHT CONDITIONS IN THE VENUSIAN ATMOSPHERE AND ESTIMATES OF THE OPTICAL CHARACTERISTICS APPLICABLE TO THE TASK OF PHOTOGRAPHING ITS CLOUDS AND SURFACE

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ABSTRACT. The authors describe the parameters of the atmosphere of Venus, light conditions in the Venusian atmosphere, and general optical characteristics of the atmosphere which are relevant to the problem of photographing the surface and clouds of Venus.

INTRODUCTION

The data obtained by direct measurement of the parameters of the Venusian atmosphere by automatic interplanetary stations [1,2] and from Earth-based observations make it possible to analyze and evaluate the optical characteristics of the atmosphere and surface of Venus. /3*

The findings can be used as initial data for developing systems of plotting and measuring radiation characteristics. They also can be used for estimating the possibility of using solar radiation to provide energy for and calculating heat conditions of a vehicle entering the atmosphere of Venus.

Evaluation of the Cloud Layer Albedo

Let us make use of the dependence of pressure P , temperature T , and density ρ upon altitude h in accordance with [2], and also of the dependence of the spherical albedo A_{sp} of Venus upon the length of the wave λ (curve 1 in Figure 1), which was obtained by Irvine from Earth-based observations.

We calculate the dependence of the spherical albedo on wavelength with the premise of the absence of the aerosol component $\bar{A}_{sp}(\lambda)$. For this we shall use the expression $E_{out}(\Psi)$ [4] for the light flux exiting from the atmosphere:

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* Numbers in margin indicate foreign pagination

$$E_{\text{out}}(\psi) = \pi S_{\lambda} \cos \psi \frac{1 - \frac{3}{2} K_1 \cos \psi}{1 + K_1} \quad (1)$$

$$K_1 = \frac{1}{\frac{1+A}{1-A} + \frac{3}{2} \Delta \tau_{r,\lambda}}$$

where ψ -zenith distance of the Sun
 A -albedo of the surface of the planet
 $\Delta \tau_{r,\lambda}^{\circ}$ -full optical thickness of the atmosphere for Rayleigh molecular diffusion
 πS_{λ} -spectral solar constant for the planet

From this we obtain the following formula for $\bar{A}_{\text{sp}}(\lambda)$:

$$\bar{A}_{\text{sp}}(\lambda) = 1 = \frac{1}{\frac{1}{1-A} + \frac{3}{4} \Delta \tau_{r,\lambda}^{\circ}} \quad (2)$$

Let us determine the initial data necessary for computing $\bar{A}_{\text{sp}}(\lambda)$.

Presently there is no information whatever on the albedo of the surface of Venus in the visible and infrared areas of the spectrum; therefore, for the analysis we shall use known data on the albedo of earth and moon rocks. In accordance with [5] and [6] we take the values: $A_{\text{max}} = 0.5$; $A_{\text{min}} = 0.02$; $\bar{A} = 0.1 + 0.2$.

By definition

$$\Delta \tau_{r,\lambda}^{\circ} = \int_0^H \sigma_{\lambda}(h) dh, \quad (3)$$

where h -altitude
 H -altitude of the upper limit of the atmosphere;
 $\sigma_{\lambda}(h)$ -coefficient of Rayleigh scattering; or

through the altitude of the homogeneous atmosphere

$$\Delta \tau_{r, \lambda} = \sigma_{\lambda} H_{*}, \quad (4)$$

σ_{λ} is computed as follows:

$$\sigma_{\lambda} = \frac{32\pi^3 (n-1)^2}{3N\lambda^4}, \quad (5)$$

where n -is the refractive index of the medium; /5
 N -is the number of diffusing particles in a unit volume,
 equal to

$$N = \frac{N_{av} \rho}{\mu}, \quad (6)$$

where N_{av} = $6.023 \cdot 10^{23}$ mole⁻¹ -Avogadro's number, |
 ρ -gas density,
 μ -molecular weight of the gas.

The refractive index of the atmosphere can be written using its temperature T and pressure P :

$$n = 1 + \beta \frac{P}{T}. \quad (7)$$

For the Venusian atmosphere, the constant $\beta = 0.13$ deg/atm.

The height of the uniform atmosphere is determined by the formula

$$H_{*} = \frac{KT}{\mu g}, \quad (8)$$

where K = $1.38 \cdot 10^{-16}$ erg/deg -Boltzmann's constant |
 g -acceleration due to gravity.

The result is the following expression for $\Delta \tau_{r, \lambda}^{\circ}$:

$$\Delta \tau_{r, \lambda}^{\circ} = \frac{32\pi^3 (\beta P)^2 K}{3N_{av} \rho \lambda^4 g T}. \quad (9)$$

In computing $\Delta \tau_{r|\lambda}^{\circ}$, it was assumed that the Venusian atmosphere consists solely of carbon dioxide and the values of the atmosphere parameters were taken in accordance with [2].

Considering the albedo of the surface $\bar{A} = 0.2$ and using (9), applying Formula (2), we get values $\bar{A}_{sp}(\lambda)$. The resulting computations of $\bar{A}_{sp}(\lambda)$ and $\Delta \tau_{r|\lambda}^{\circ}$ are presented in Table 1 and by curve II in Figure 1. From the figure it is evident that in the range of wavelengths below 0.6 micron considerable absorption may take place. /6

The Earth-based observations of Venus indicate the existence of dark sections in the upper layers of its atmosphere which can be observed only by using light filters that prevent the passage of radiation longer than 0.6 micron, which serves as an additional indirect confirmation of the existence of absorption in the shortwave region. In the region of wave lengths above 0.6 micron, the observed spherical albedo has a higher value than the value of the albedo of pure gas.

If we consider the scattering of light in the region of wavelengths above 0.6 micron as conservative, we can evaluate the albedo of the cloud layer that causes the value of the spherical albedo to be higher than the albedo of pure gas. For computing the albedo of the cloud layer on the basis of [4], we have the expression

$$A_{cl} = 1 - \frac{1}{\frac{1}{1 - A_{sp}} - \frac{3}{4} \Delta \tau_{r|\lambda}^{\circ} - \frac{A}{1 - A}} \quad (10)$$

The computation of A_{cl} by (10) with the albedo of the subjacent surface $A = 0 - 0.4$ indicates that this albedo is practically constant throughout the range of wavelenths from 0.62 to 1.06 microns and that it equals 0.87-0.88. Inasmuch as the absence of marked absorption was presupposed here, the obtained value is an estimate of the albedo of the cloud layer from below. Assuming that the constancy of cloud layer albedo in relation to the wavelength is caused by the large size of its component parts, it is possible to compute on the basis of (4) the optical thickness of the cloud layer $\Delta \tau_{cl}$. Such computations lead to a value of the order of 60. Conversely, with the assumption that A_{cl} is constant /7

and equals 0.87 and $A = 0.2$, it is possible to compute with the use of formula (11) the spherical albedo for various wavelengths.

$$A_{sp, \lambda} = 1 - \frac{1}{\frac{3}{4} \Delta \tau_{cl}^0 + \frac{1}{1 - A_{cl}} + \frac{A}{1 - A}} \quad (11)$$

The data of the computation, marked with triangles in Figure 1, are in good agreement with experimental curve 1. The value of the optical thickness of clouds $\Delta \tau_{cl} = 60$ also agrees well with the estimates obtained by A. S. Ginsburg and Ye. M. Feygel'son in [7] for a model with minimal concentration of H_2O .

The Effect of the Planet's Surface Radiation

We shall compute the planet's surface radiation in the range of wave lengths that we deal with in order to determine the longwave boundary of the spectral range of photography. The absolute distribution of energy in the spectrum of the planet's surface radiation can be arrived at by the formula

$$I_{\lambda} = \epsilon_{\lambda} B_{\lambda} (T_{\eta}), \quad (12)$$

where I_{λ} - is the monochromatic intensity,
 ϵ_{λ} - is the radiation factor,
 $B_{\lambda} (T_{\eta})$ - is the intensity of blackbody radiation with temperature T_{η} .

Taking the surface of Venus as a blackbody, i.e., $\epsilon_{\lambda} = 1$, and recording $B_{\lambda} (T_{\eta})$ in accordance with Planck's law we will have

$$I_{\lambda} = \frac{C_1 \lambda^{-5}}{C_2 \left(\frac{1}{\lambda T_{\eta}} \right) - 1} \quad (13)$$

where $C_1 = 1.19 \cdot 10^8 \text{ W sterad}^{-1} \cdot \text{m}^{-2} \cdot \text{mc}^4$
 $C_2 = 14350 \text{ micron degrees}$
 $T_{\eta} = 768^{\circ} \text{K}$

The results of the computation of the planet's surface radiation by formula (13) are presented in the form of a graph in Figure 2. The maximum monochromatic intensity corresponds to the wave length λ_{\max} which is determined according to Wien's displacement law:

$$\lambda_{\max} T_{\eta} = 2880 \text{ micron degrees} \quad (14)$$

and its value is 3.75 microns.

Thus, in choosing the longwave boundary of the spectral range of photography, equaling 1 micron, the background natural surface radiation of the planet will be practically excluded. The above analysis of the experimental data testifies to the possibility of considerable absorption of radiation in the Venusian atmosphere with $\lambda \ll 0.6$ micron. In accordance with the above, further computations will examine the spectral region from 0.6 to 1 micron.

Estimation of the Distribution with Altitude of the Atmosphere of Luminous Fluxes and Contrasts

Inasmuch as the obtained values and dependencies upon the albedo wavelength and the thickness of the cloud layer seem to be quite real, there is no reason to assume the existence of considerable absorption in the range under study, at least not in the highest layers of the atmosphere. In order to obtain (under conditions of the absence of absorption) an evaluation from below of the illumination below a certain level above the planet's surface, we must assume that the main mass of the aerosol component is located above this level. For specific computations we selected as an example the level that corresponds to the pressure of 0.56 atmospheres and, according to [1], an altitude of 57 km above the surface of the planet. /9

The calculation of the distribution of illumination in the layer beneath the clouds was done in accordance with the theory presented in [4]. The formula for the luminous flux falling from the upper hemisphere on an area perpendicular to the radius vector to a given point (ψ, h) appears as follows:

$$E_{\text{in}}(h, \psi) = \frac{1}{2} \pi S_{\lambda} \cos \psi \left(1 + \frac{3}{2} \cos \psi \right) \frac{1 - A_{\text{sp}\lambda}}{1 - A_{\text{r}\lambda}(h)}, \quad (15)$$

$$0 \leq \psi \leq 89^{\circ}$$

and the expression for $A_{\text{r}\lambda}(h)$ is determined as follows:

$$A_{\text{r}\lambda}(h) = 1 - \frac{1}{\frac{3}{2} \Delta \tau_{\text{r}\lambda}(h) + \frac{1}{1-A}}, \quad (16)$$

where $\Delta \tau_{\text{r}\lambda}(h)$ is the optical thickness of the layer at altitude h (h is

calculated from the surface of the planet). Values of $A_{sp\lambda}$ are taken on the basis of Irvine's data (Figure 1, Curve 1).

The data from computation of height distribution of illumination are presented in Figure 3 (a-d). The calculations were made at four positions of the Sun $\psi = 0^\circ, 30^\circ, 60^\circ$ and 89° for $\lambda = 0.6, 0.7, 0.8$ and 0.9 micron. The integral energy illumination under the clouds ($h = 57$ km, $P = 0.56$ atm) in the range of wavelengths from 0.6 to 1.06 microns with $\psi = 0$ is on the order of $400 \text{ W/m}^2/$ | /10

The findings depend upon the accuracy of determinations of $A_{sp\lambda}$ and $A_{r,\lambda}$. A change of pressure at the surface by 15-20%, i.e., a change by 3 km in the height of the surface of Venus, has relatively little effect on the determination of $\Delta\tau_{cl}$ and the illumination under the clouds. At the same time, however, the increase of $A_{sp\lambda}$ by 3% leads to doubling the value of $\Delta\tau_{cl}$ and, correspondingly, to a decrease of illumination under the clouds by approximately 50%.

Inasmuch as there might be breaks in cloud formations, it becomes interesting from the standpoint of photography to estimate the contrasts that arise under such conditions.

In order to obtain top view estimation of contrasts, we must also assume that the principal part of the aerosol component is located in the upper portions of the atmosphere. However, if the clouds are considerably stratified, the observed contrasts can be considerably less. Since for the gaseous layer the indicatrix of scattering is nearly spherical, we may consider the boundary of the gaseous layer as an orthotropic surface. For the sake of simplicity, let us assume that the boundary of the cloud layer is also an orthotropic surface; then, according to [4], contrasts in cloud observation are computed by the formula

$$K_{abv \text{ cl}} = \frac{\frac{1}{\frac{2}{1-A} + \frac{3}{2} \Delta\tau_{r,\lambda}^0} - \frac{1}{2} (1 - A_{sp\lambda})}{\frac{1}{1 + \frac{3}{2} \cos\psi} - \frac{1}{2} (1 - A_{sp\lambda})} \quad (17)$$

The findings are presented in Table 2. As we can see from Table 2, contrasts in observations of clouds from above decrease with an increase of ψ . | /11

The contrasts determined by (17) constitute a certain averaging of contrasts observed at zenith angles ϑ . Actual contrasts $K_{abv\ c1}$ will be greater than the contrasts presented in Table 2; near the peaks of the reflective indicatrix they will coincide with a certain average angle ϑ_{av} and will be less for all other angles.

Estimations of Brightness Characteristics of the Surface

The brightness characteristics of the surface in the chosen spectral range (0.6 - 1 micron) are determined by its illumination and reflectivity. Because nothing is known about the relationship of the albedo of the Venusian surface to the wavelength, we shall consider the spectrum of reflected radiation to be similar to the spectrum of inward radiation. The reflecting power of the surface is characterized by the brightness coefficient

$$\bar{r} = r_0 f(i, \epsilon, T), \quad (18)$$

where r_0 is a constant that determines the absolute value of the reflectivity, and $f(i, \epsilon, T)$ is a function that determines the relative change of reflectivity depending upon the angles of incidence i , reflection ϵ and azimuth difference T of the incident and reflected rays.

Because of the great optical thickness of the Venusian atmosphere, the illumination of its surface is achieved by completely diffused radiation. The intensity of radiation at great optical thickness does not depend upon the azimuth, but is a function of zenith distance ϑ (8): /12

$$I(\tau_0, \vartheta, \psi) = S \bar{\sigma}(\vartheta, \psi) \cos \psi, \quad (19)$$

where the sky brightness coefficient $\bar{\sigma}(\vartheta, \psi)$ is written in the following manner:

$$\bar{\sigma}(\vartheta, \psi) = \frac{(1 + \frac{3}{2} \cos \psi) [(1-A)(1 + \frac{3}{2} \cos \vartheta) + 2A]}{4 + (3 - \tilde{x}_1) (\Delta \tau_{r, \lambda}^0 + \Delta \tau_{c1}) (1-A)}, \quad (20)$$

where \tilde{x}_1 is a parameter of the diffusion indicatrix averaged over the thickness of the atmosphere.

For this reason the brightness of the surface does not depend upon the azimuth. The distribution of brightness depending upon the angle ϵ for the horizontal small area will be proportional to the distribution of the sky brightness (ϵ corresponds to ϑ in expression (19)), if the surface (on the basis of its reflection indicatrix) belongs to the mirroring type. With a different reflection indicatrix, the distribution of surface brightness will approach the orthotropic, i.e., ($i, \epsilon, \phi = 1$ and $r| = r|_0 = \text{const.}$

For the orthotropic surface, the brightness coefficient \bar{r} is written simply by using the flat albedo A [5]

$$r| = r|_0 = \frac{A}{\pi} \quad (21)$$

and the brightness of the surface is determined from its illumination in the following manner: /13

$$B = \bar{r}|E_\eta = \frac{A}{\pi} E_\eta. \quad (22)$$

The computation of the natural illumination of the surface is actually the solution of a direct problem. Consequently, in doing this, a specific model of the Venusian atmosphere is used. Two cases should be examined:

- a) Absorption of radiation takes place in the atmosphere of Venus in the range of wavelengths over 0.6 micron;
- b) No absorption, and there is only diffusion of radiation.

Because there are no data on absorption in the Venusian atmosphere, let us determine the upper limit of illumination. In the case of pure diffusion the illumination of the surface is determined by (15) with $A_{r,\lambda}$ being equal to the albedo of the surface.

The results of the calculation of natural illumination obtained by (15) with the use of (16) and (9) are presented in Figure 4 (a-e). Figure 4a illustrates the dependence of monochromatic illumination of the surface $E_{\eta,\lambda}$ upon the wavelength for various values of surface albedo A and zenith distance of the Sun $\psi = 80^\circ$. Figure 4b portrays a similar dependence at various values of solar zenith

distance ψ and surface albedo $A = 0.1$. Figure 4c shows the dependence of monochromatic illumination $E_{\eta,\lambda}$ for various wavelengths and integral illumination $E_{\eta,\Sigma}$ upon the value of the surface albedo A with solar zenith distance $\psi = 80^\circ$. Figure 4d illustrates dependencies of the same values upon the zenith distance of the Sun ψ with the surface albedo $A = 0.1$. Figure 4e is a graph of the dependence of integral surface illumination upon the solar zenith distance with various values of surface albedo. /14

Using the illuminations obtained and the corresponding surface albedos it is possible to compute the brightness of the surface using (21).

Let us analyze possible contrasts on the surface of Venus. The fundamental causes of the appearance of the contrasts are:

- 1) the presence of small areas with different surface albedos,
- 2) the presence of surface roughness.

As was pointed out above, nothing is presently known about the albedo of the surface of Venus in the visible and near infrared regions of the spectrum; therefore, we cannot draw any conclusions regarding contrasts caused by the difference in surface albedos, i.e., the possible range of contrasts 0-1.

With directed illumination the roughness of the surface usually causes the appearance of shadows and, consequently, of contrasts. Because direct solar emission practically does not reach the surface of Venus and it is illuminated by diffuse radiation, there are no shadows on its surface. Nevertheless, because of the roughness of the surface, contrasts may take place. They are caused by the fact that surfaces with various slopes are illuminated by fluxes of radiation contained in different solid angles and coming from various sections of the sky, which affects the spatial distribution of the brightness of these surfaces. Let us examine the case when the small areas are orthotropic. Then the expression for contrast can be formulated thusly:

$$K = \frac{B_{\eta\max} - B_{\eta\min}}{B_{\eta\max}} = \frac{E_{\eta\max} - E_{\eta\min}}{E_{\eta\max}} \quad (23)$$

Let us determine the illumination of areas A, B, and C (Figure 5a) in the immediate vicinity of their intersection.

The illumination of the area is expressed as follows:

$$E_{\text{area}} = I \cos \vartheta d\omega, \quad (24)$$

where I is the intensity of the radiation and
 ω is a solid angle.

In a polar system of coordinates with the Z-axis directed along the normal to the area, the element of the solid angle is

$$d\omega = \sin \vartheta d\vartheta d\mathcal{T}. \quad (25)$$

Then the illumination of the horizontal area is

$$E_{\eta} = \int_0^{2\pi} d\mathcal{T} \int_0^{\frac{\pi}{2}} I \cos \vartheta \sin \vartheta d\vartheta. \quad (26)$$

The intensity of illumination at the surface is determined by (19).

Into the expression for $\bar{\sigma}(\vartheta, \psi)$ (20), let us introduce the following designations:

$$a = \frac{1 + \frac{3}{2} \cos \psi}{4 + (-\tilde{x}_1)(\Delta \tau_{r, \lambda}^{\circ})(1-A)} \quad (27) \quad \underline{/16}$$

$$b = 1 + A$$

$$c = \frac{3}{2} (1-A)$$

hence

$$\bar{\sigma}(\vartheta, \psi) = a(b + c \cos \vartheta). \quad (28)$$

With the use of (19), (26), and (27) we obtain the illumination of Area A (Figure 5a):

$$E_{\text{Area A}} = \int_0^{2\pi} d\mathcal{T} \int_0^{\frac{\pi}{2}} S \cos \psi a(b + c \cos \vartheta) \cos \vartheta \sin \vartheta d\vartheta = 2a \pi \cos \psi. \quad (29)$$

Radiation comes from the atmosphere to Area C with values $\frac{\pi}{2} + \beta \leq \vartheta \leq \frac{\pi}{2}$; radiation, reflected from Area B, which has surface albedo A, corresponds to angles $-\frac{\pi}{2} \leq \vartheta < -\frac{\pi}{2} + \beta$. Therefore, the illumination of Area C assuming a single reflection equals

$$E_{\text{Area C}}(\beta) = F(0, \frac{\pi}{2}) + F(0, -\frac{\pi}{2} + \beta) + AF(-\frac{\pi}{2} + \beta, -\frac{\pi}{2}) =$$

$$= \pi S a \cos \psi \left\{ \frac{1}{2} b [1 + A + (1 - A) \cos^2 \beta] + \left[\frac{1}{3} c \left(2 - (1 - A) \sin^3 \beta \right) \right] \right\}, \quad (30)$$

where

$$F(x, y) = \int_0^{\pi} \int_x^y S \cos \psi a (b + c \cos \vartheta) \cos \vartheta \sin \vartheta d\vartheta.$$

For the determination of the illumination of Area B we shall use another system of coordinates with the axis Z', normal to the given area (see Figure 5a). The angle γ read off this axis is linked to angle ϑ by the relationship $\vartheta = \gamma - \beta$. Taking into account the reflection from Area C (albedo of the surface A) we record the illumination of Area B:

$$E_{\text{Area B}}(\beta) = \phi(0, \frac{\pi}{2}) + \phi(0, \frac{\pi}{2} + \beta) + A\phi(\frac{\pi}{2} + \beta, \frac{\pi}{2}) =$$

$$= \pi S a \cos \psi \left\{ \frac{1}{2} b [1 + A + (1 - A) \cos^2 \beta] + \frac{1}{3} c [2 \cos \beta + (1 - A) \sin \beta - (1 - A) \sin \beta \cos \beta] \right\}, \quad (31)$$

where

$$\phi(x, y) = \int_0^{\pi} d\vartheta \int_x^y S \cos \psi a [B + c \cos(\gamma - \beta)] \cos \gamma \sin \gamma d\gamma.$$

Using (27), (29), and (31) we obtain the expression for the contrast between Areas A and B as a function of β , the slope angle of Area B

$$K_{AB} = \frac{E_{\text{Area A}} - E_{\text{Area B}}}{E_{\text{Area A}}} = 1/4 (1 - A) (1 - \cos \beta) [(1 + A)(1 + \cos \beta) - (1 - A) \sin \beta + 2] \quad (32)$$

This dependence at low surface albedos ($A \leq 0.1$) is stated graphically in Figure 5b. A similar dependence can be obtained for the contrast between Areas B and C.

The above ideas regarding contrasts on the surface are also justifiable in the case of nonorthotropic areas. The spatial distribution of surface brightness will then be additionally affected by its indicatrix of reflection.

This is graphically illustrated by Figure 5c, which demonstrates the distribution of brightness of two mirror surfaces, horizontal and sloping. /18

Estimation of the Decrease of Contrast with Altitude

The maximum altitude for photographing the surface will be determined by the allowable decrease in local contrast on rising above the surface. For this reason it is necessary to obtain the relationship of the decrease in contrast to height for various wavelengths. The contrast at altitude h can be expressed through the brightness of the surface B_{surface} , the brightness of the scattered radiation in the gas layer between the surface and the camera B_{scat} and the optical thickness of this layer $\Delta\tau$ in the following manner:

$$K_h = \frac{B_{\text{surface max}} e^{-\Delta\tau} - B_{\text{surface min}} e^{-\Delta\tau}}{B_{\text{surface max}} e^{-\Delta\tau} + B_{\text{scat}}} \quad (33)$$

Then the attenuation of the contrast at height h in comparison with the contrast at the surface K_0 will be written as follows:

$$\frac{K_h}{K_0} = \frac{1}{1 + \frac{B_{\text{scat}} e^{\Delta\tau}}{B_{\text{surface max}}}} \quad (34)$$

Taking (22) into account and the fact that

$$B_{\text{scat}} = B_{\text{gas}} - B_{\text{area}} e^{-\Delta\tau}, \quad (35)$$

where B_{gas} is the brightness of the gaseous layer, we obtain the expression for the decrease in gas contrast with altitude through the illumination of the surface E_{surface} and the gas layer E_{gas} , and the corresponding albedos: the maximum A_{max} and average \bar{A} of the surface and the average albedo of the gas-- \bar{A}_{gas} : /19

$$\frac{K_h}{K_0} = \frac{1}{1 + \frac{\bar{A}_{\text{gas}} E_{\text{gas}} z^{\Delta\tau} - \bar{A}_{\text{area}} E_{\text{area}}}{A_{\text{max}} E_{\text{area}}}} \quad (36)$$

Using (15) and (16) and taking into account that in this case $E_{\text{in}}(h, \psi) = E_{\text{gas}}$ and $\Delta\tau_{r\lambda}(h) = \Delta\tau$, after transformations we will have the dependence of the decrease in contrast on the optical thickness of the gas layer $\Delta\tau$ with given surface albedos:

$$\frac{K_h}{K_0} = \frac{1}{1 - \frac{\bar{A}}{A_{\text{max}}} + \left[\frac{\bar{A}}{A_{\text{max}}} + \frac{3(1-\bar{A})}{4A_{\text{max}}} \Delta\tau \right] z^{\Delta\tau}} \quad (37)$$

The graph $\frac{K_h}{K_0} = f(\Delta\tau)$ is shown in Figure 6a (assuming $\bar{A} = 0.1$; $A_{\text{max}} = 0.2$).

In order to link the decrease in contrast to the change in altitude, it is necessary to know the connection between the altitude and the optical thickness of the gas corresponding to it. For the arbitrary altitude h we have the analogy (3)

$$\tau = \int_h^H \sigma_\lambda(h) dh, \quad (38)$$

and $\sigma_\lambda(h)$ is determined by (5), (6), and (7). Designating all constants in the expression $\sigma_\lambda(h)$ by M_λ and using the relationship

$$\frac{\rho}{\rho_0} = \frac{P}{P_0} \cdot \frac{T_0}{T}, \quad (39)$$

we can transcribe it in the following form:

$$\sigma_\lambda(h) = M_\lambda \left(\frac{P_0}{T_0 \rho_0} \right) \rho = M'_\lambda \rho, \quad (40)$$

In the case of a polytropic atmosphere the gas density appears as:

$$\rho = \rho_0 \left(\frac{T_0 - \gamma h}{T_0} \right)^{\frac{\mu g}{\gamma R} - 1}, \quad (41)$$

where γ is the vertical temperature gradient, and

R is the gas constant.

Substituting (40) and (41) into (38) and integrating, we will have

$$\tau = M'_\lambda (T_0 - \gamma h) \frac{\mu g}{\gamma R}. \quad (42)$$

Excluding the constant M'_λ , we write

$$\frac{\tau h}{\tau_0} = \left(\frac{T_0 - \gamma h}{T_0} \right) \frac{\mu g}{\gamma R} \quad (43)$$

or

$$\frac{\tau_0 - \Delta\tau}{\tau_0} = \left(1 - \frac{\gamma}{T_0} h \right) \frac{\mu g}{\gamma R}. \quad (44)$$

Altitudes corresponding to given $\Delta\tau$ for various wavelengths are presented in Table 3. With the use of functions $\frac{K_h}{K_0} = f(\Delta\tau)$ and $\Delta\tau = f(h)$, it is possible to determine the decrease of contrast with altitude for various wavelengths. This dependence is presented graphically in Figure 6b, where Curve I corresponds to $\lambda = 0.9$ micron; II - $\lambda = 0.8$ micron; III - $\lambda = 0.7$ micron; IV - $\lambda = 0.6$ micron. /21

Contrasts between large areas, caused by the difference of albedos of these areas A_1 and A_2 , according to [4] change with altitude according to the formula

$$\frac{K_h}{K_0} = \frac{1}{\left[1 + \frac{3}{4} \frac{1-A_1}{A_1} \Delta\tau_{r_1}(h) \right] \left[1 + \frac{3}{4} (1-A_2) \Delta\tau_{r_2}(h) \right]}. \quad (45)$$

If $0.1 \leq A_1 \leq A_2 \leq 0.3$ then A_1 and A_2 in (45) can be replaced with a sufficient degree of accuracy by $\bar{A} + \frac{A_1 + A_2}{2}$. The relationship (45) for $\bar{A} = 0.1$ and 0.2 is presented graphically in Figure 6c (Curves I-IV correspond to the same wavelengths as in Figure 6b).

In case the atmosphere is dusty near the surface of the planet, the loss of contrast with altitude will occur faster. Computations with (37) and (45) yield maximum contrast values for the optical image at the focal plane of the objective.

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TABLE 1 SPHERICAL ALBEDOS AND RAEYLEIGH OPTICAL THICKNESS

λ , microns	$\Delta \tau_{r,\lambda}^{\circ}$	$\bar{A}_{sp, \lambda}$	$A_{sp, \lambda, \rho}^u$
0,300	222,0	0,994	0,994
0,400	67,0	0,980	0,982
0,500	27,4	0,954	0,965
0,626	11,2	0,895	0,938
0,700	7,06	0,85	0,923
0,800	4,15	0,770	0,908
0,900	2,59	0,686	0,895
1,06	1,4	0,560	0,886

(Commas indicate decimal points)

TABLE 2 CONTRASTS IN OBSERVATION OF CLOUDS FROM ABOVE (ESTIMATES FROM ABOVE)

λ Microns \ ψ°	0°	30°	60°	80°	89°
0,626	0,061	0,054	0,042	0,030	0,024
0,700	0,104	0,082	0,070	0,050	0,040
0,800	0,200	0,182	0,133	0,094	0,076
0,900	0,294	0,269	0,197	0,137	0,110

(Commas indicate decimal points)

TABLE 3 RELATIONSHIP BETWEEN OPTICAL THICKNESS OF GASEOUS LAYER AND ALTITUDE ABOVE THE SURFACE OF VENUS

λ_i	τ													
	0,01	0,05	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1	2	3
1 0,6	13,2	63,1	126,5	256	384	513	640	770	898	1025	1197	1280	2690	4700
2 0,7	16,6	116	231	470	710	975	1230	1470	1720	1975	2230	2490	5330	10000
3 0,8	33,2	201	402	811	1230	1650	2095	2565	2965	3490	3960	4455	10220	18800
4 0,9	66,4	316	658	1309	2035	2735	3490	4260	5060	5910	6800	7710	21300	

(Commas indicate decimal points)

Figure 1. Dependence of Spherical Albedo A_{sp} of Venus on Wavelength λ

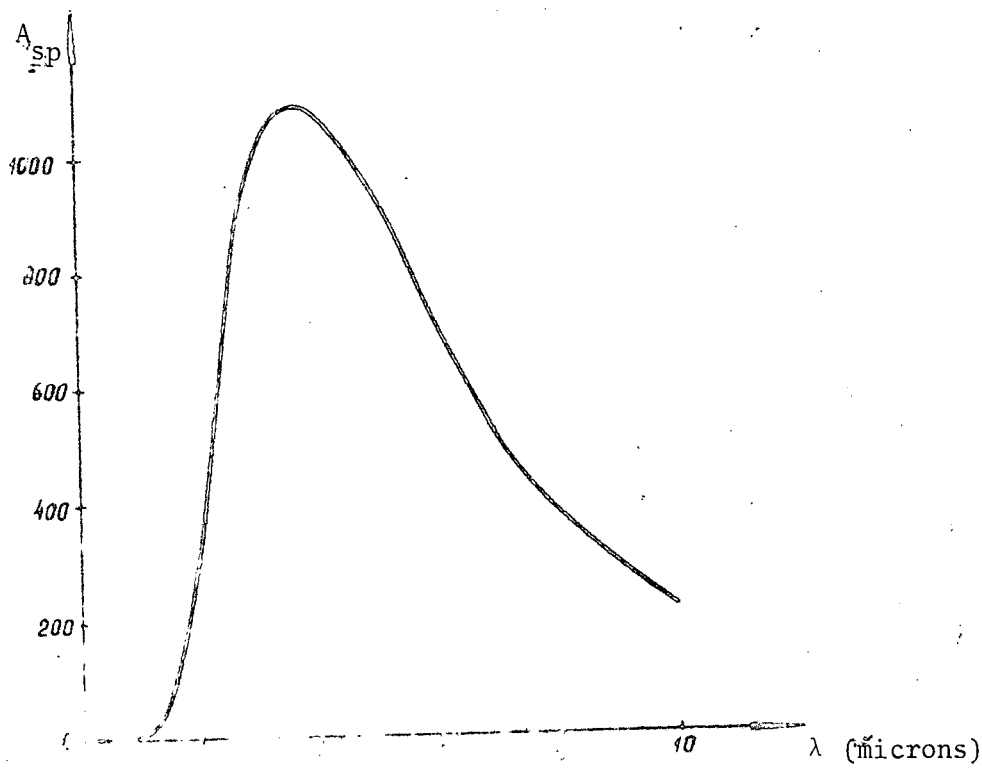
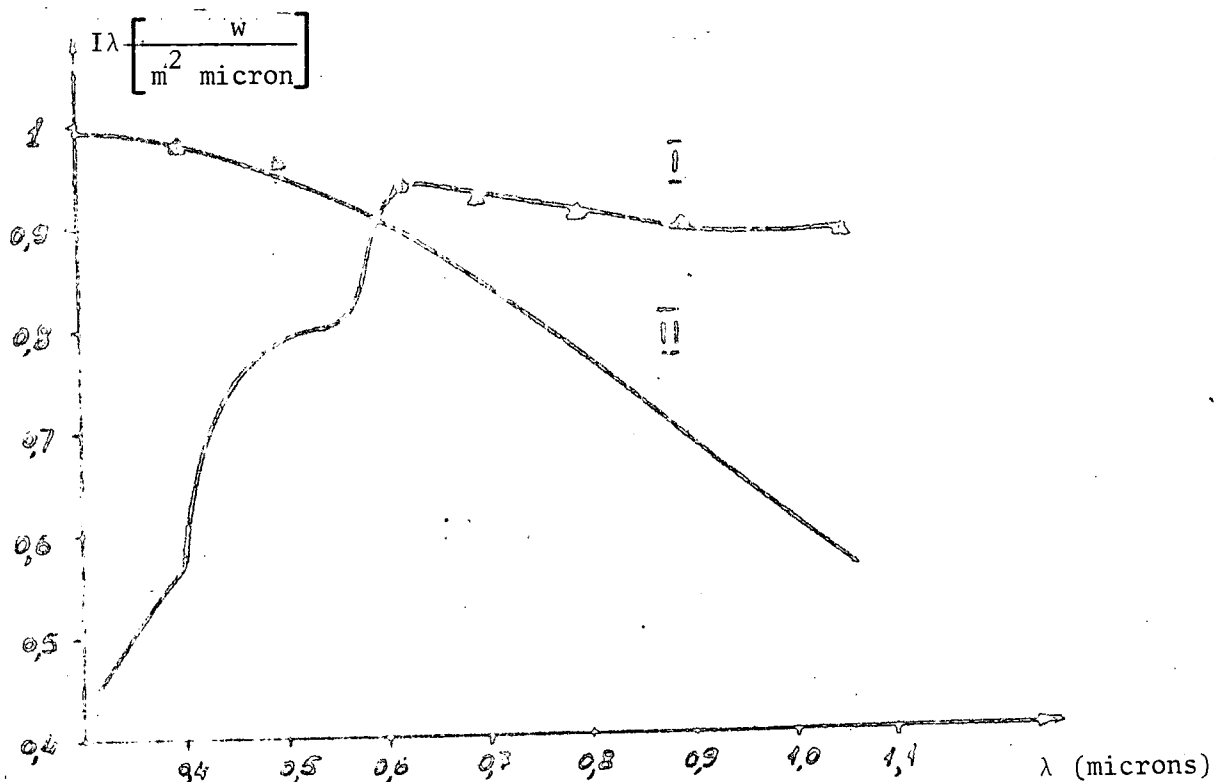
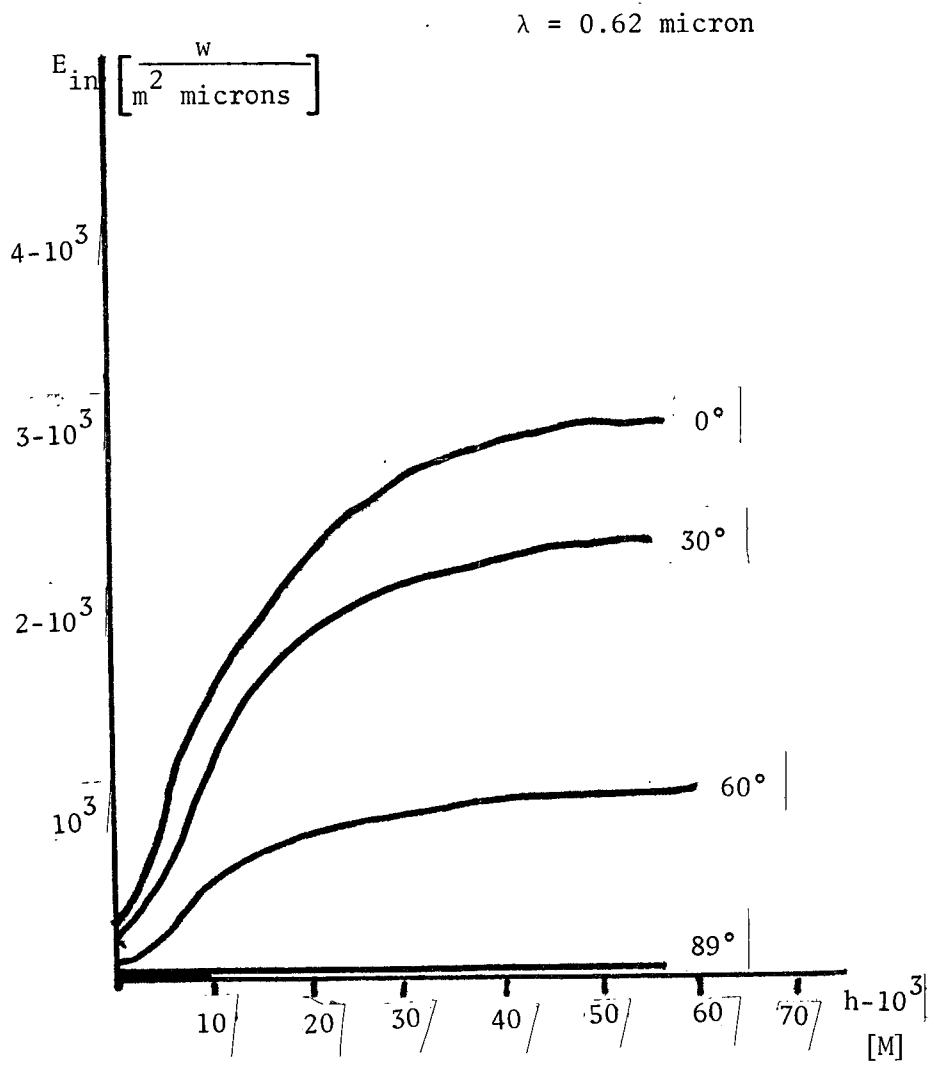


Figure 2. Dependence of the Natural Surface Radiation of the Planet
on Wavelength λ



Commas indicate decimal points.

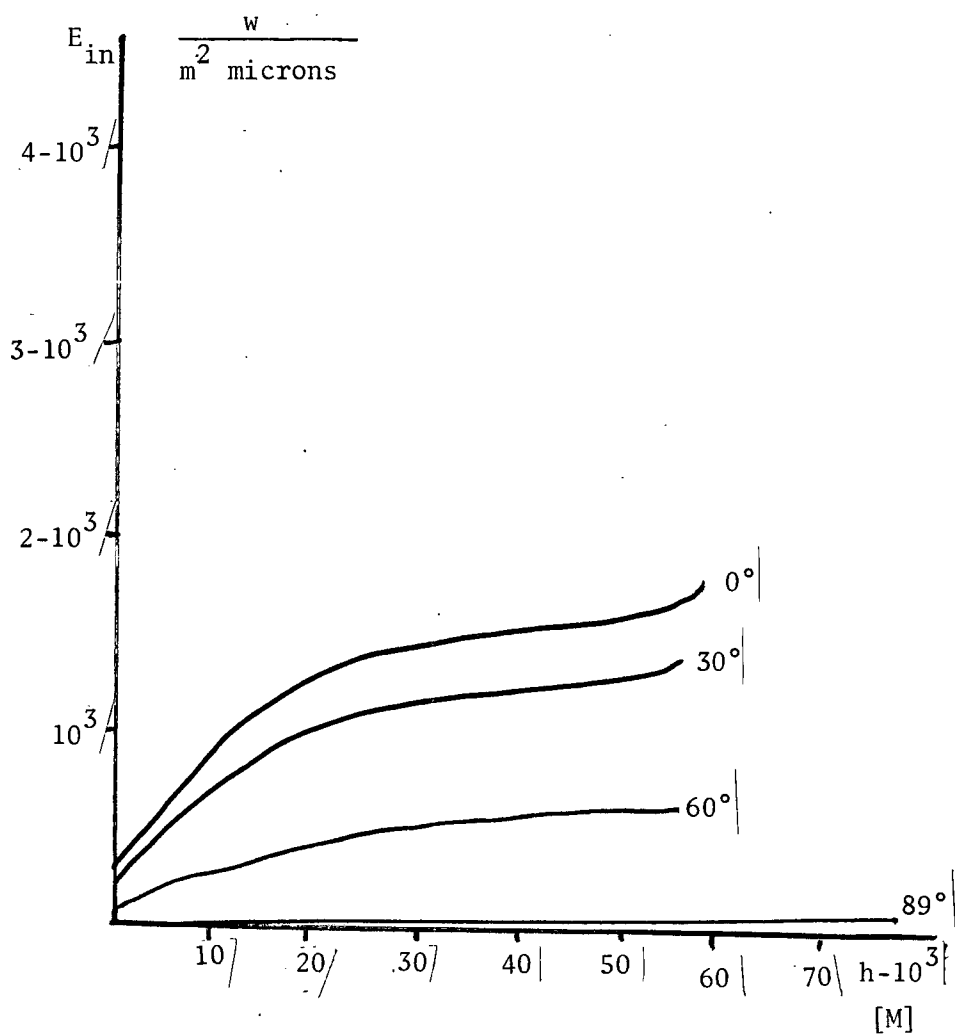
Figure 3 (a through d). Distribution of Illumination With Altitude



a,

Figure 3 (cont.)

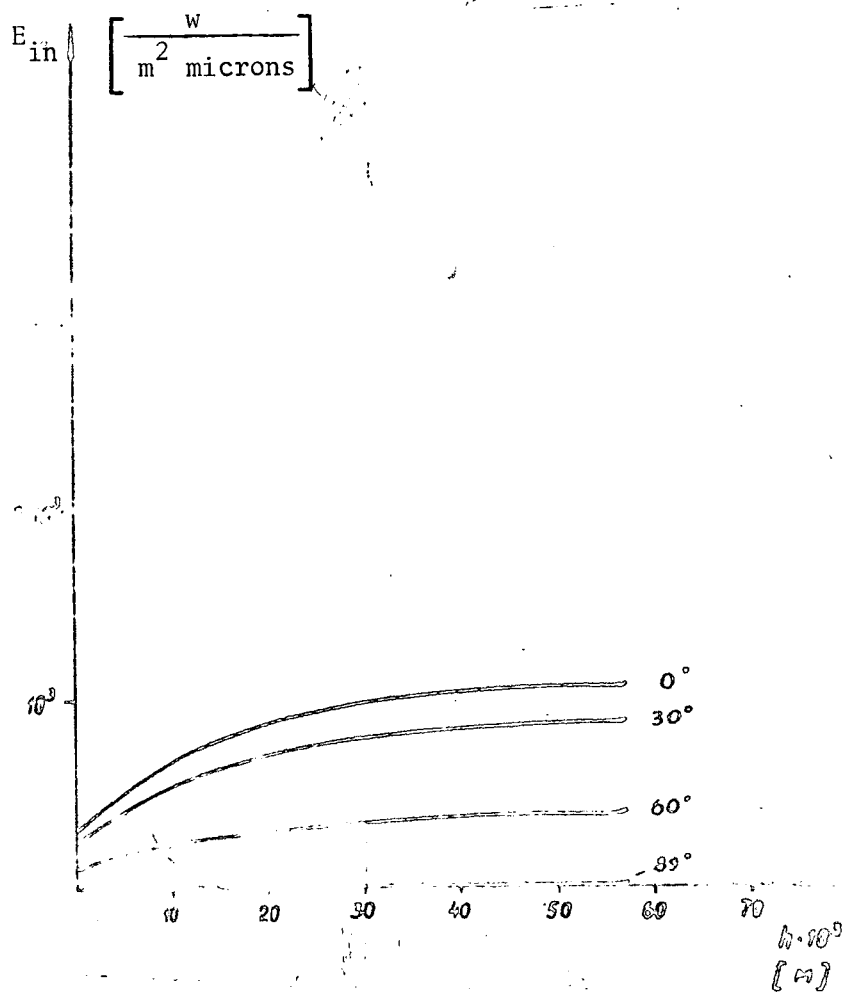
$\lambda = 0.7$ micron



b,

Figure 3 (cont.)

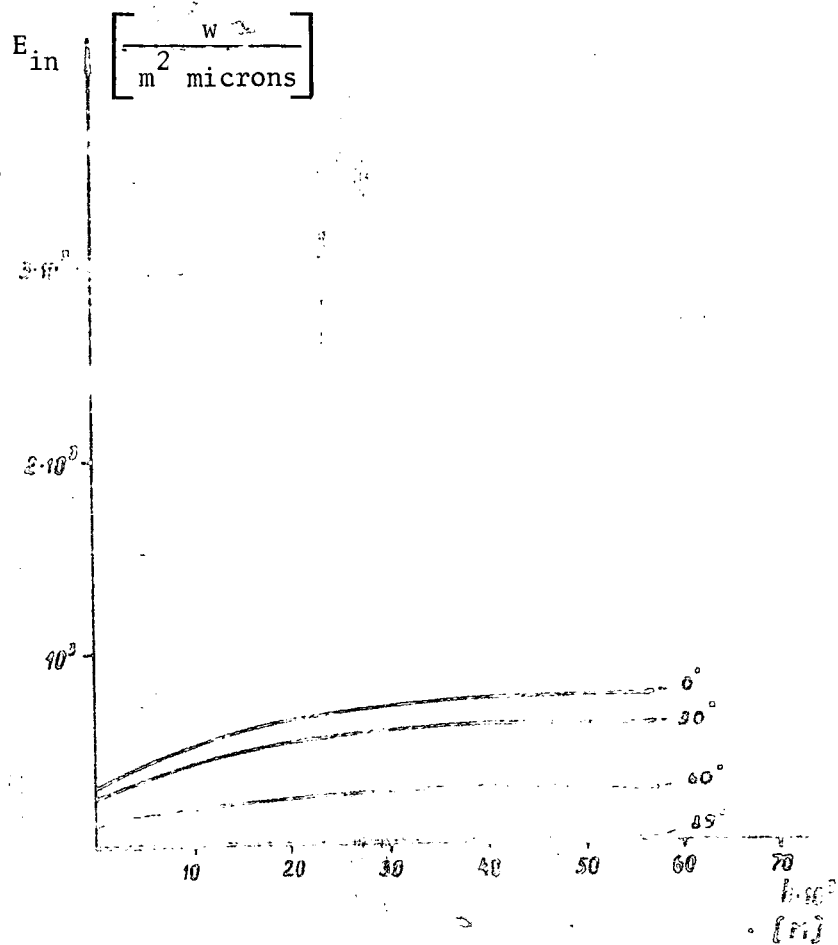
$\lambda = 0.8$ micron



c,

Figure 3 (cont.)

$\lambda = 0.9$ micron



d)

Figure 4 (a through e). Dependence of Monochromatic Illumination of the Surface of the Planet:

a, On wavelength with various values of A and with $\psi = 80^\circ$

b, On wavelength with various values of ψ and $A = 0.1$

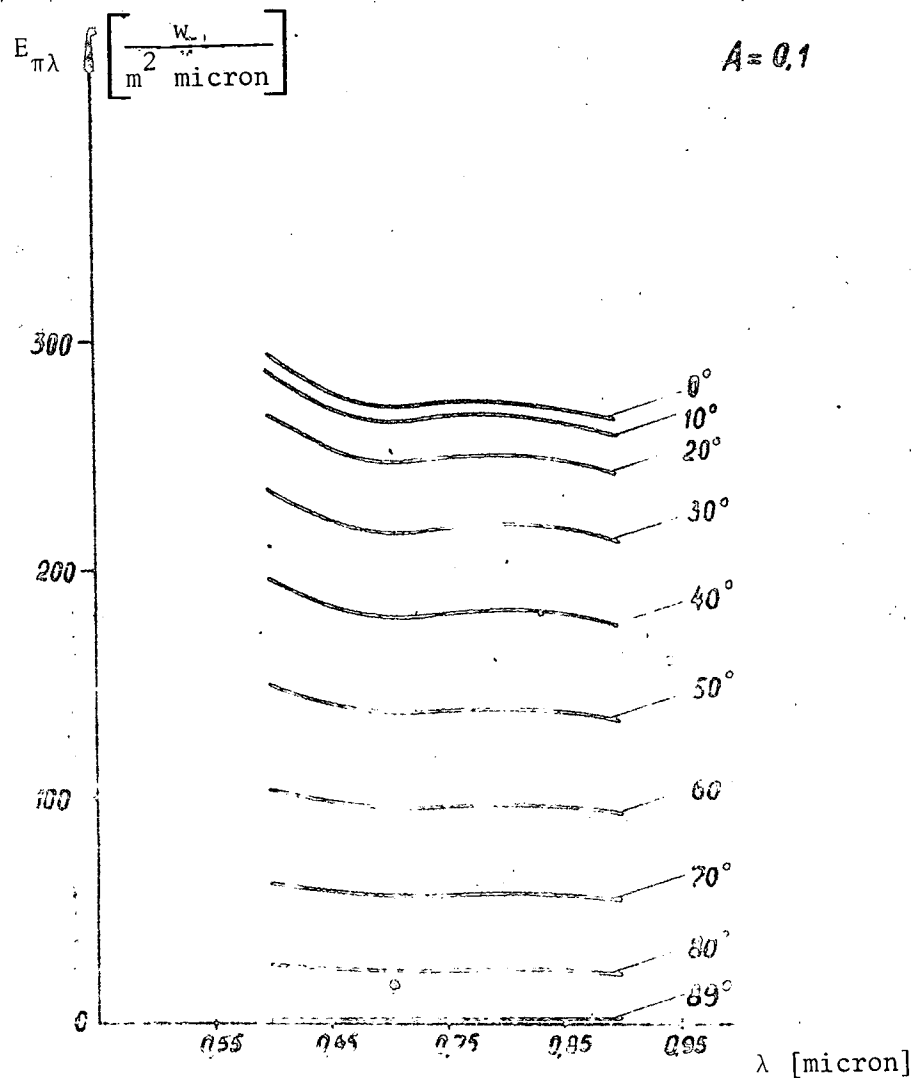
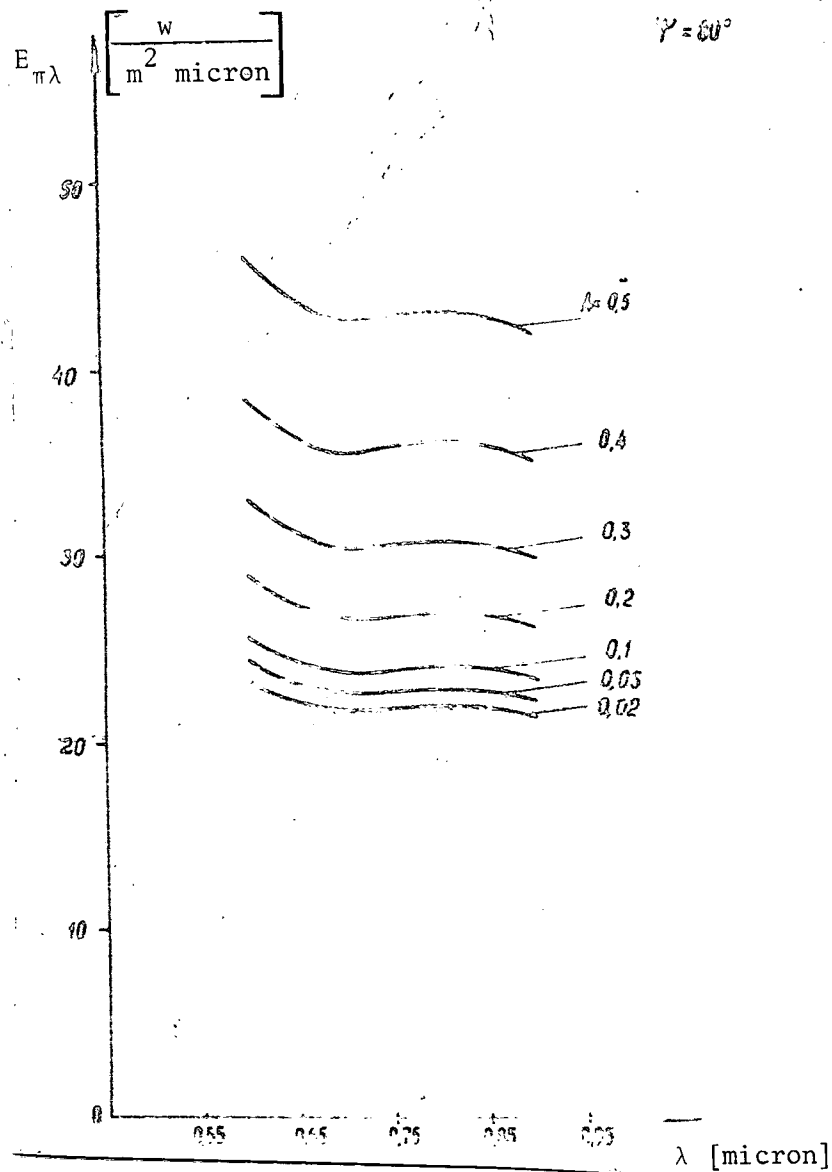
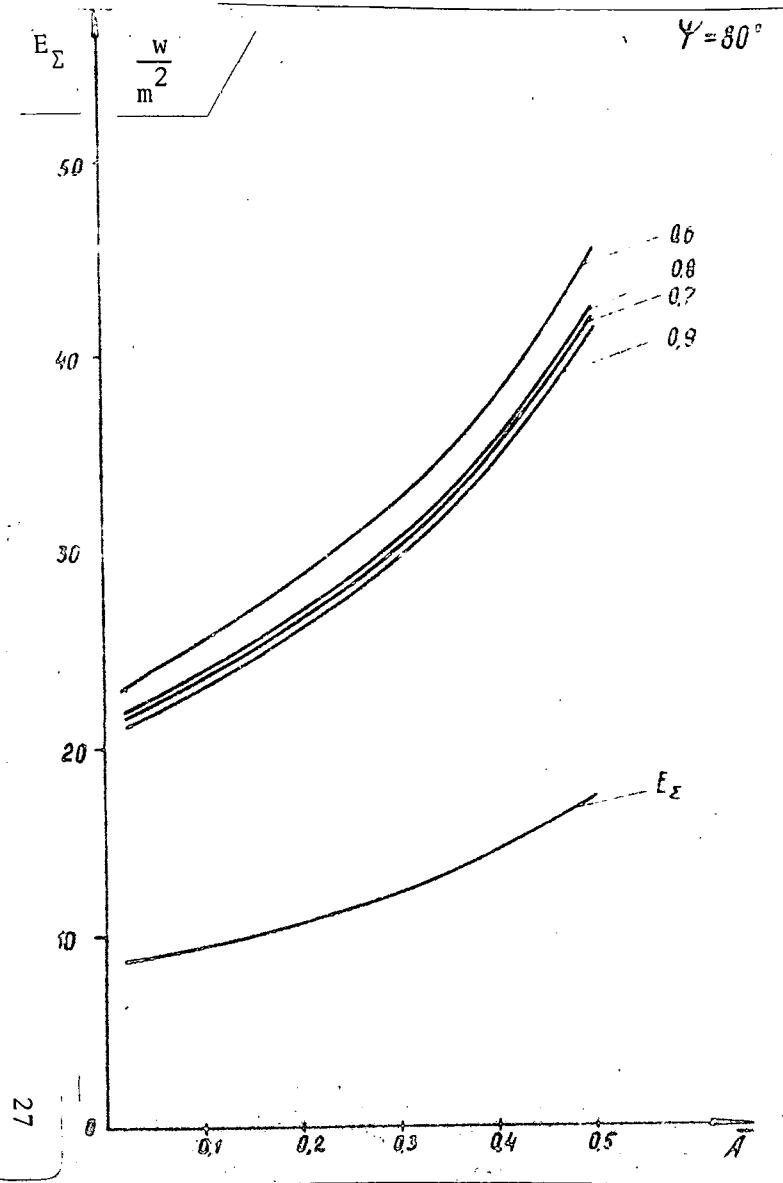


Figure 4 (cont.).

c, On the surface albedo value at various wavelengths with $\psi = 80^\circ$



d, On the Sun angle with $A = 0.1$

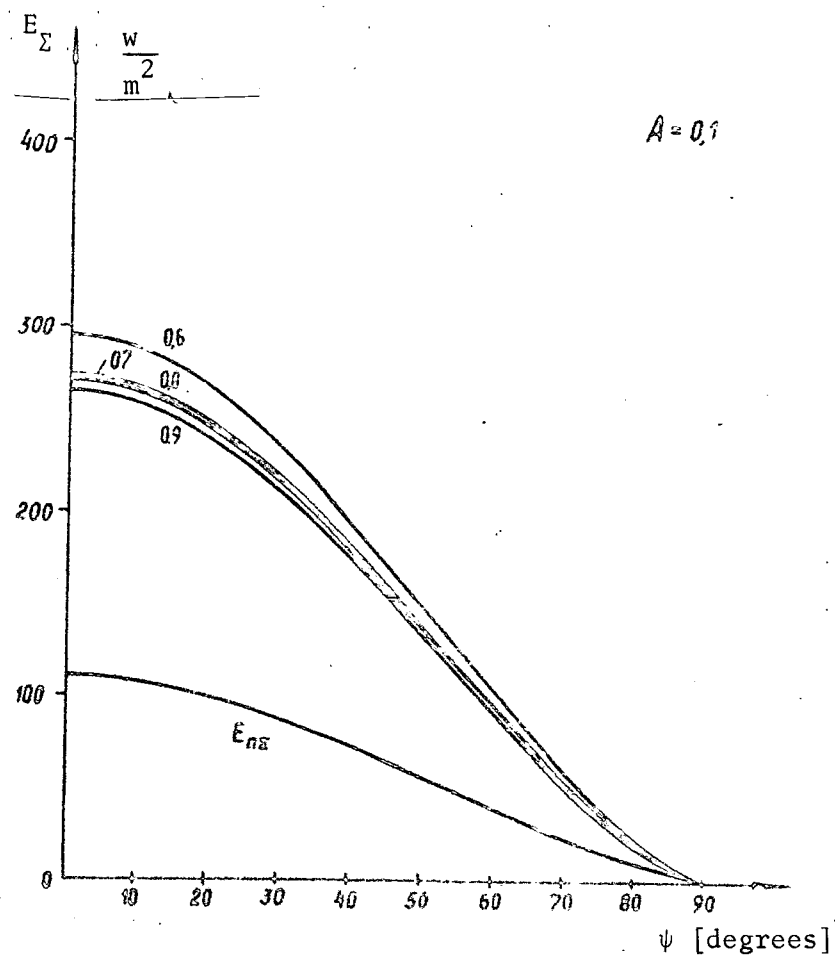


Figure 4 (cont.).

e, Dependence of integral illumination of the surface on Sun angle ψ at various albedo values.

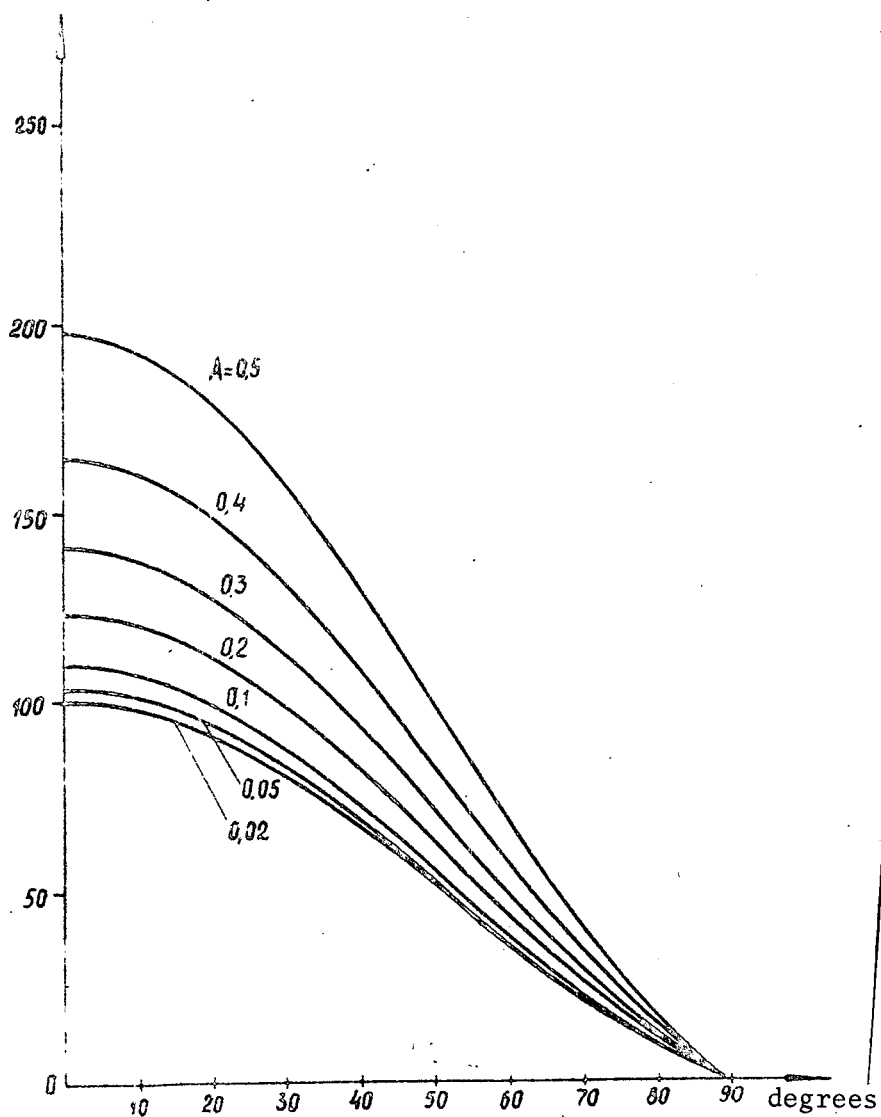


Figure 5 (a). The Effect of the Slope of the Area on the Contrast Distribution on the Surface

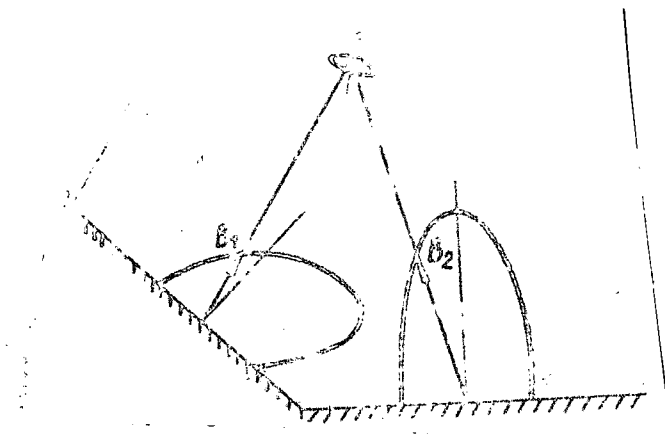
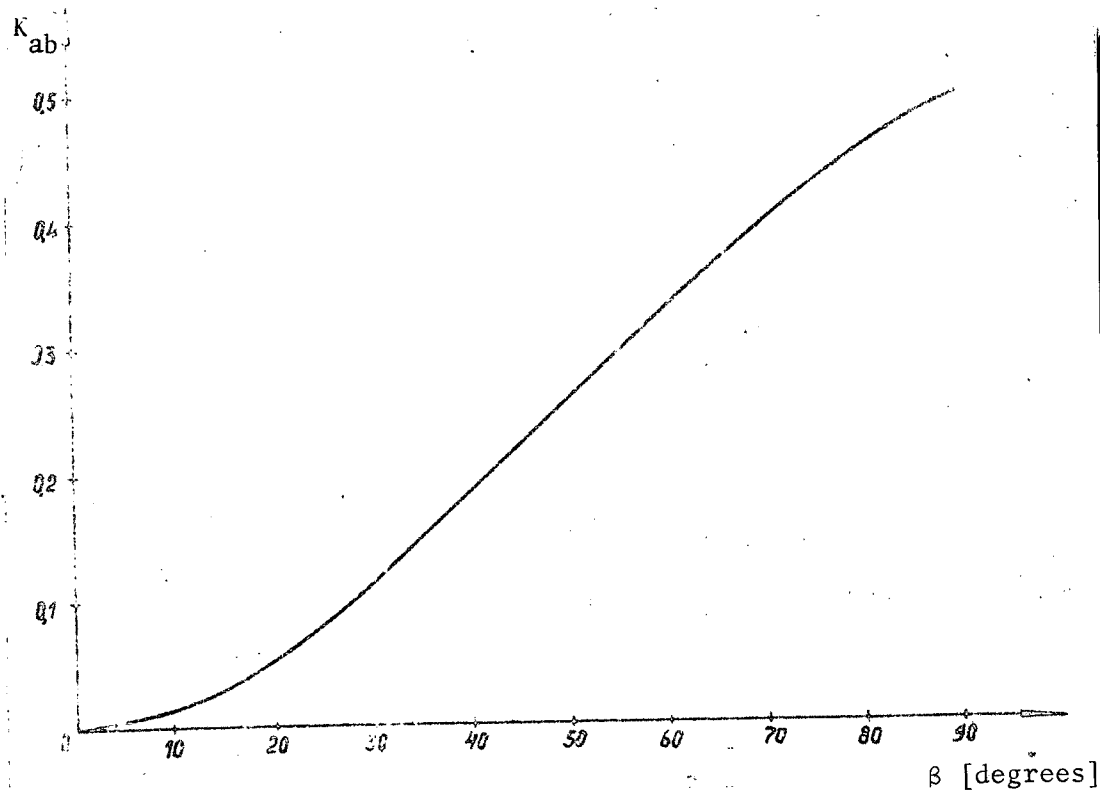


Figure 5 (b). Dependence of Contrast between Areas A and B upon the Slope Angle β of the Area



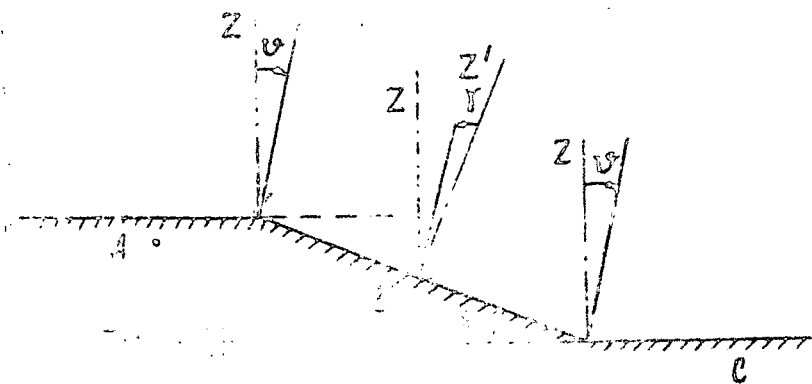


Figure 5 (c). For Computation of Contrast on the Surface

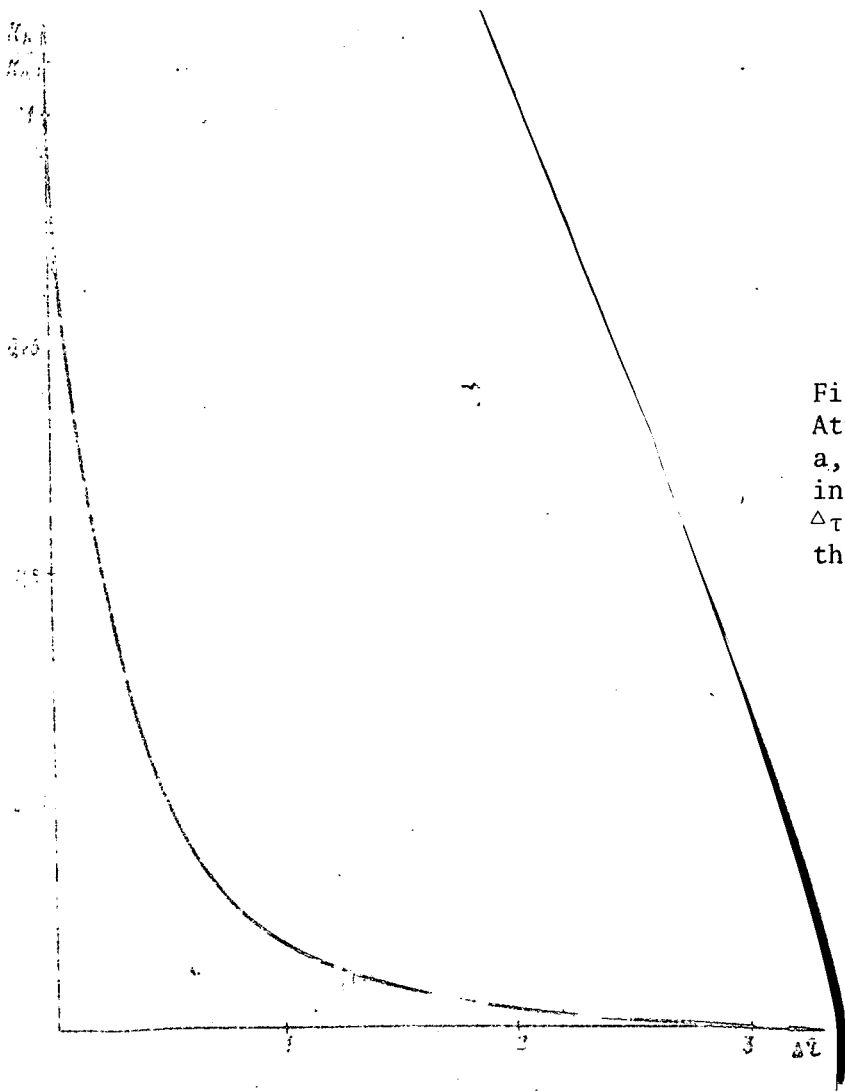
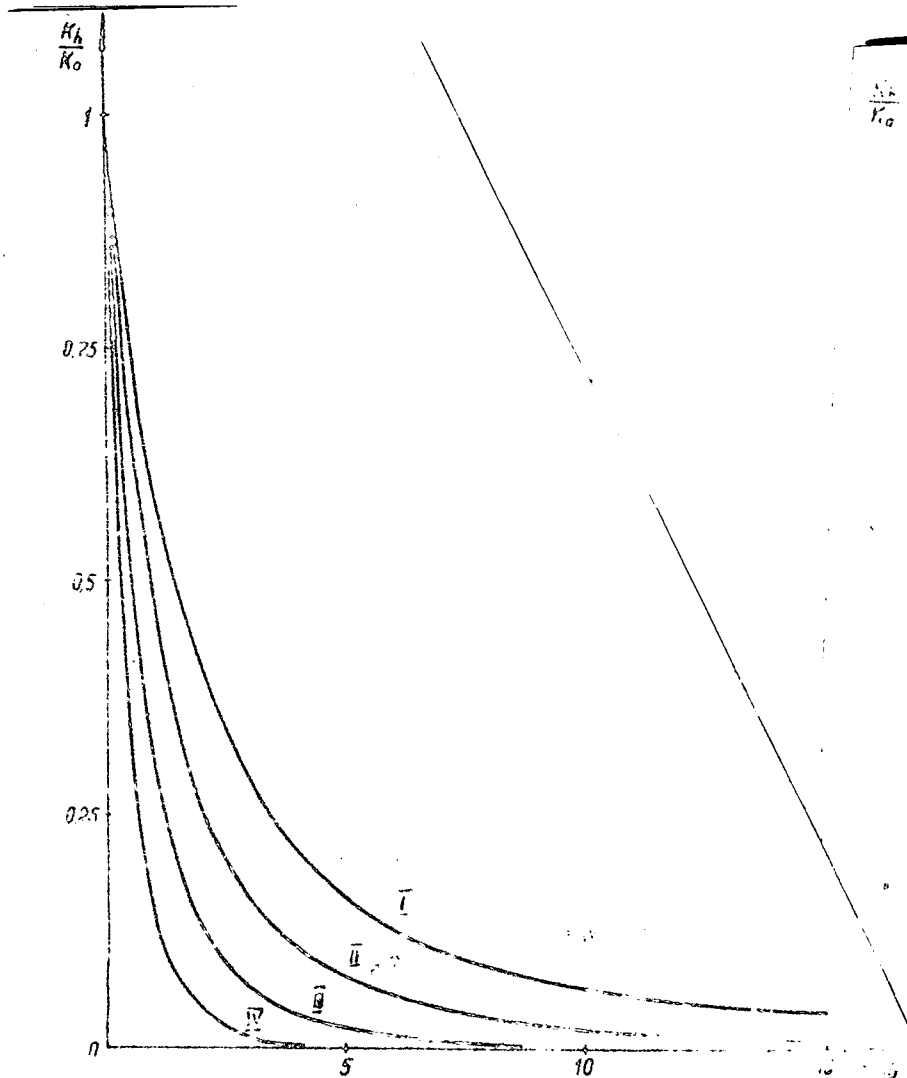


Figure 6 (a through c). Attenuation of Contrast a , Depending upon Changes in the Optical Altitude $\Delta\tau$ above the Surface of the Planet

Figure 6 (cont.).

b, Depending upon h --the Altitude
above Surface for small Areas



c, The same for large areas

